29 Designing Feedback to Mitigate Distraction

Birsen Donmez, Linda Boyle, and John D. Lee

CONTENTS

29.1 INTRODUCTION

The rapid development of sensor, wireless communication, and computing technology has given rise to a range of devices that are capable of entertaining, informing, and supporting the driver (e.g., MP3 players, cellular phones, and navigation systems). However, these devices may also undermine safety due to conflicts between the demands of the in-vehicle system and the demands of driving. Part 7 of this book describes design approaches that reduce the demands associated with using in-vehicle information system (IVIS) functions while driving. Technology that can assist in mitigating distraction in real time include warning the driver about dangerously high levels of distraction, locking out functions (see Chapter 26), or having a system adapt appropriately to the degree of distraction experienced by the driver (see Chapter 28). Such technology mainly focuses on enhancing immediate driving performance (i.e., real-time performance when the technology takes action to mitigate distraction). Another approach to mitigate distraction is to provide feedback to the driver to enhance immediate performance as well as to induce a positive behavioral change, such as diminishing the willingness to engage in future distracting activities to enhance long-term driving performance.

Feedback within the context of this chapter can be defined as the information provided to the driver regarding the state of the driver-vehicle system. Immediate driving performance (e.g., lane position) is feedback inherent in the driving task that can be enhanced with additional feedback provided via an in-vehicle system. For example, feedback can be provided as alerts to warn the driver of critical roadway situations (e.g., lane drift signaled by virtual rumble strips) or high levels of distraction. Changes can occur very rapidly in the driving environment, and the driver may fail to track these changes, particularly if the driver's attention is directed toward a nondriving-related activity or if the driver is cognitively loaded.[1–4] In such situations, feedback can help the driver respond to these changes (e.g., lead vehicle braking) more appropriately. Feedback can provide a warning to the driver based on a hazardous situation (e.g., lane deviation warning), can help the driver learn what is unsafe (e.g., failure to reduce speed during bad weather conditions), and can ultimately alter driver behavior (e.g., inhibiting knowingly risky behavior such as speeding).

Drivers currently receive feedback that shapes their immediate response to the driving situation and their long-term behavior. For example, there are educational messages provided on billboards or in radio or television media (e.g., "don't drink and drive," "click it or ticket"), variable message signs, radar speed display signs, and by law enforcement and driving instructors. Each medium or person provides some feedback on what drivers should be doing or have already done in the hope that they will correct their behavior on future drives. However, such feedback is dependent on the environment, is not tailored to the behavior of the individual, and may be absent in some situations. For example, there is no means by which to consistently provide feedback when a driver looks away from the road for a dangerously long period of time. Furthermore, existing feedback is not tailored to the driver, and drivers do not receive moment-to-moment feedback regarding their performance. Therefore, such feedback may have little influence on drivers' behavior. Emerging technology can circumvent the limits of current feedback and may provide an effective means by which to mitigate distraction as well as alert the driver to other inappropriate behavior. Different feedback characteristics (e.g., positive or negative feedback) can facilitate these outcomes differently. This chapter describes characteristics of different feedback types and the benefits they can provide for enhancing performance and modifying driver behavior such as reducing drivers' willingness to engage in distractions.

A three-dimensional taxonomy has previously been proposed to define different distraction mitigation strategies that focus on enhancing immediate driving performance.[5–8] These dimensions include the degree of automation of the mitigation strategy, the type of initiation, and the type of task that is being modulated by the strategy. The degree of automation can range from a simple driver alert signal to complete system control. These automation levels can be initiated either by the driver or the automation and can modulate either the driving task or the in-vehicle task. This chapter proposes another dimension in designing distraction mitigation strategies—the temporal dimension—which considers the immediate effect of the system on driving performance as well as the long-term effect on drivers' willingness to engage in a distracting activity. Changing behavior, such as the willingness to engage in a distracting activity, may have a particularly powerful influence on safety.[9] Providing feedback is promising because drivers may not always realize the potential hazards created from decisions to engage in a distracting activity, may not always make the safest choice in doing so, and often experience no negative consequences for a poor choice. Feedback may enhance immediate performance, but this effect may not always be sustained once feedback is removed, unless it can provide information that updates the driver's internal model of safe driving, thereby resulting in a behavioral change. There is a need to develop design strategies that can mitigate the effects of driver distraction on immediate driving performance and to encourage safer long-term driving habits. Current driving literature is very limited with respect to different feedback timescales. Therefore, much of this chapter is based on theoretical assertions that are grounded in research conducted in other domains. More research is needed to investigate the effects of different feedback timescales on driving performance and behavior.

29.2 TIMESCALES OF FEEDBACK

There are four major timescales that can be designed in a distraction mitigation system: concurrent (milliseconds), delayed (seconds), retrospective (minutes, hours), and cumulative (days, weeks, months). Figure 29.1 suggests that as the timescale of feedback extends, the goal of feedback will change from improving immediate driving performance to inducing safer driver behavior. For example, concurrent (i.e., real-time) feedback can improve performance of the driver who has just departed his or her lane and

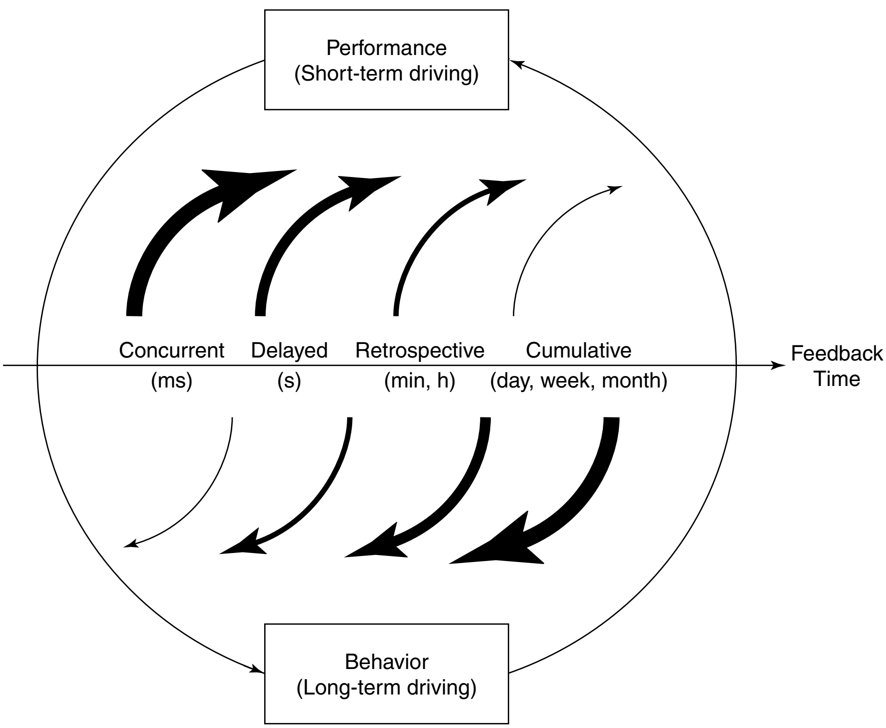

FIGURE 29.1 Levels of feedback timing and the magnitude of targeted influence (indicated by arrow thickness).

should discontinue a cell phone conversation. This concurrent feedback may improve the driver's lane-keeping performance, but might not influence the driver's willingness to use a cell phone during the next trip. However, accumulating and reporting to the driver the number of lane departures over months can make the driver more aware of how cell phone conversations cause these departures, and this may diminish the driver's willingness to engage in this activity while driving. The following sections discuss the pros and cons of each feedback timescale, which are summarized in Table 29.1. Each of these feedback timescales is also incorporated into a driver information–processing model that provides insights for designing distraction mitigation systems.

29.2.1 Driver Information–Processing Model with Temporal Feedback

The driver information–processing model with temporal feedback encompasses five stages (Figure 29.2). Four of these stages (i.e., intention, perception, cognition, and action) and the disturbances to these stages from the physical or cognitive distracters (e.g., cell phones) are based on a model presented by Sheridan.[10] Sheridan's information-processing model is modified here in two ways: (1) the revised model alters the interaction between distracters and the intention stage, and (2) it also adds a new stage—"internal model of safe driving."

Sheridan[10] defines the intention stage as creating a "priority-ordered sequence of near-term driving goals." This definition focuses on driving only and excludes driver intentions to engage in distracting activities. However, the driver's intentions will set goals for both the driving and the nondriving tasks. To capture the intent to engage in distracting activities (both driving and nondriving related), this model includes a link from the intention stage to the distracters, suggesting that distractions can be initiated by the driver. Distracters can also create disturbances that influence the driver's intentions, and thus, the link is bidirectional. Providing feedback to inhibit the driver's intentions to engage in distractions can enhance safety.

Sheridan's[10] model assumes that the basic intention of the driver is to drive safely regardless of any additional tasks undertaken. However, the definition of safe driving can vary among individuals and change over time. To capture this effect, a fifth stage is included in the model to represent the internal model of safe driving (i.e., a driver's belief of acceptable behavior while driving). Interactions also exist among these five stages. For example, the driver's perception of the environment can update intentions, and cognition can guide perception by directing attention to different aspects of the environment. Feedback to the internal model of safe driving has potential to alter driving behavior. Feedback that directly helps with intention and perception has potential to enhance immediate driving performance. Each feedback timescale has a different degree of influence on these stages. The following sections define each feedback timescale in detail and describe how these timescales affect behavior and immediate performance.

29.2.2 Concurrent Feedback

Concurrent feedback can be presented to the driver in real time when there is a resource conflict between driving and distracters. For example, if the driver is distracted, or if the driver fails to respond appropriately to a roadway demand,

TABLE 29.1
Potential Pros and Cons for Different Feedback Timescales

Timescale	Pros	Cons
Concurrent feedback	• Immediate implications for enhancing driving performance when feedback is present • Can help the driver learn safe maneuvers (e.g., safe following distance)	• Driver may adapt to feedback inappropriately • May elevate the level of cognitive distraction if feedback is not intuitive to the driver • Low acceptance can lead to disuse of feedback • Overreliance on feedback can result in dangerous situations if feedback fails • Can interfere with immediate task performance • Unexpected lags can undermine the effect of feedback • Deterioration of productivity (i.e., in-vehicle information system [IVIS] task performance)
Delayed feedback	• Informs the driver about correct and incorrect driving behavior while avoiding cognitive overload • Can enhance driving performance during a trip for upcoming events • Can help the driver learn safe maneuvers (e.g., safe following distance)	• Feedback is not provided at the time of the incident and can therefore not enhance immediate driving performance • Unexpected lags can undermine the effect of feedback • Deterioration of productivity (i.e., IVIS task performance) • Low acceptance may lead to disuse
Retrospective feedback	• Intentions leading to unsafe driving behavior can be explained to the driver without cognitive overload • Can enhance driving performance for future trips • Can refresh drivers' memory on performance for the completed trip • Can calibrate driver's subjective performance by presenting a connection between intentions and events that occurred during a trip	• Feedback is not provided at the time of the incident and can therefore not enhance immediate driving performance • Requires the driver to be an active recipient of information • Driver may fail to link feedback with incident • Low acceptance may lead to disuse
Cumulative feedback	• Intentions leading to unsafe driving behavior can be explained to the driver without cognitive overload • Can enhance driving performance for future trips • Can refresh driver's memory on performance for past trips • Can calibrate driver's subjective performance by highlighting persistent behavior that leads to errors	• Feedback is not provided at the time of the incident and can therefore not enhance immediate driving performance • Requires the driver to be an active recipient of information, however people may not take the time to review this type of feedback • Driver may fail to link feedback with incident • Low acceptance may lead to disuse

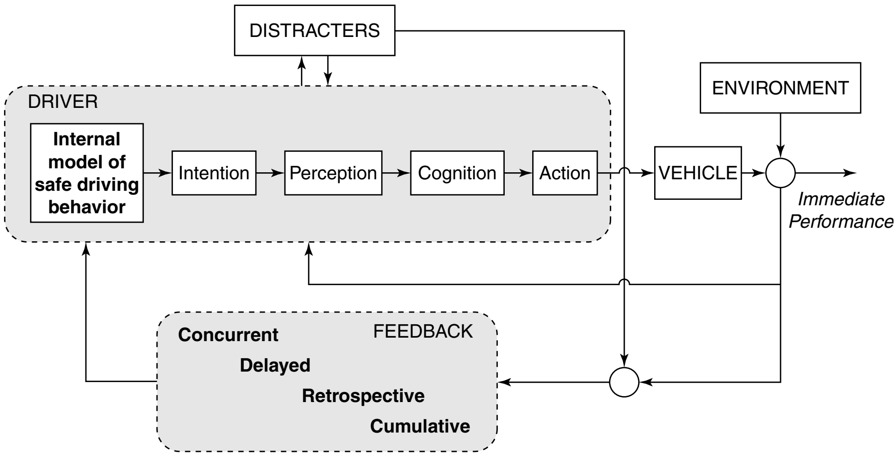

FIGURE 29.2 The process by which driver responds to feedback at different timescales.

concurrent feedback would remind the driver to discontinue the in-vehicle task and direct attention to the roadway. Therefore, concurrent feedback can directly enhance driving performance. Warnings are forms of concurrent feedback, and the literature related to warnings in the driving domain is vast.[11–14] A comprehensive discussion of concurrent feedback in the driving domain is also provided by Donmez.[15]

The effects of concurrent feedback based on the driver's momentary distraction level has been previously investigated.[8] The results suggest that concurrent feedback can help drivers modulate their distracting activity. Specifically, the study showed that concurrent feedback (a visual alert on the in-vehicle display) based on drivers' distraction level decreased the glance frequency to the in-vehicle display while increasing the glance duration to the road between in-vehicle glances. However, concurrent feedback may not be completely effective in mitigating distraction and may even exacerbate distraction. Drivers may become dependent on feedback to identify hazardous situations and may not respond appropriately if the feedback mechanism fails. For example, drivers may become more comfortable with engaging in a cell phone conversation while they are driving if they depend on the collision avoidance system to warn them when their distraction places them in a dangerous situation. This dependence can compromise driver safety if the warning system is unreliable. It is also possible that, with increased dependence, drivers may eventually filter out warnings when they are distracted.

In addition to drivers' inappropriate dependence on feedback, another concern with unreliable feedback is its potential to undermine driver acceptance,[5] which may lead drivers to ignore (or disuse) concurrent feedback.[16] Unreliable feedback can include false positives and false negatives. False-positive feedback (false or nuisance alarms) is information provided when there is no need for it. False-negative feedback is information not provided when there is a need for it. High false alarm rates can lead to driver frustration, which can also undermine traffic safety.[17] However, not all false-positive alarms are harmful. Such alarms can be used to train novice drivers, and help drivers become familiar with the system. False-positive alarms may also lead to more cautious driving and thereby result in reduced false alarm rates.[13,18] Thus, for a warning system to be effective, an acceptable false alarm rate should be established. The reliability of feedback is a major issue regardless of feedback timing. The concerns about driver acceptance, trust, and reliance also hold for feedback in longer timescales.[19]

Another reason why concurrent feedback may not be completely effective in mitigating distraction is that it may interfere with immediate task performance. Research confirms this in radar monitoring[20] and in driving.[21] Because of the limited processing time and resources available during driving, concurrent feedback may impose additional task load on the driver. One way to avoid possible information overload but still inform the driver about inappropriate behavior is to delay feedback for several seconds, until the demand decreases. Feedback at this timescale is described further in the following section.

29.2.3 Delayed Feedback

Delaying feedback by even a few seconds might avoid overloading the driver, but this delay may also diminish possible improvements to immediate driving performance. Therefore, when compared with concurrent feedback, delayed feedback may center more on altering driver behavior and less on enhancing immediate driving performance. Altering behavior, such as decreasing the driver's willingness to engage in distractions, would in turn enhance immediate driving performance.

In the driving domain, delayed feedback has been investigated by only a few researchers.[2,21] In one such system, Car Cognitive Adaptive Computer Help (CarCoach), feedback provided is canceled or delayed when the driver is cognitively overloaded.[21] The algorithms used in CarCoach define cognitive overload as occurring in two situations: (1) the driver has been making many mistakes in spite of receiving much feedback, or (2) the driver appears unusually busy with a particular driving task not generally performed while driving, such as backing up. Considering only these two situations may not define cognitive overload adequately. Drivers may be cognitively overloaded even if they are not making a lot of mistakes. Thus, a better way to evaluate cognitive overload may be to assess convergent data from physiological and performance measures. Using CarCoach, Sharon et al.[2] demonstrated that better performance was possible if undistraced drivers were guided to a more gradual acceleration by slightly delaying instructional messages on their acceleration behavior (until the acceleration maneuver was over) when compared to concurrently presenting the messages. These results suggest that notifying drivers about abrupt braking or steering maneuvers might be an effective way to enhance driver behavior. This study had limitations, including the lack of a baseline condition (i.e., no feedback), which makes it difficult to recommend any of the feedback timings (i.e., concurrent, delayed) as capable of enhancing driving performance when compared with no feedback. The existence of only a few studies (e.g., Refs 2 and 21) on delayed feedback and the limitations of these studies suggest that further research is needed on this feedback timescale.

There are some additional concerns that need to be investigated to ensure effectiveness of delayed feedback. Because driving and in-vehicle tasks are carried out in an interlaced fashion, these tasks can be viewed as mutually interrupting.[22] A potential concern of these interruptions is the initial decrease in performance as the interrupted task is resumed.[23] In addition to the safety considerations associated with the interruption of the primary task of driving by an in-vehicle task, productivity issues may also arise as in-vehicle tasks are interrupted by the need to shift attention back to the road. Therefore, even if the main objective of concurrent and delayed feedback is to enhance safety, a successful design should also aim to enhance driver productivity in interacting with the IVIS, or at least protect this productivity from deteriorating. Concurrent feedback and delayed feedback are likely to undermine productivity because they occur during the course of a trip and would therefore have the potential to interfere with IVIS interactions.

Delayed or concurrent feedback can help drivers understand whether a maneuver they are performing is unsafe. For example, providing concurrent feedback, such as a warning when the driver gets too close to a lead vehicle, can help the driver learn safe minimum stopping zones. Other unsafe driving behavior, such as talking on a cell phone while changing lanes, can also be corrected with concurrent or delayed feedback. However, due to the limited processing capacity of a driver, it may be difficult to fully explain the reasons for feedback while he or she is driving.

29.2.4 Retrospective Feedback

Retrospective feedback is defined on the temporal scale as information provided immediately after a trip is complete and not while driving. It provides information to the driver about appropriate and inappropriate behavior for the most recently completed trip. Measures can include the duration of eyes off the road, and number of distracting tasks performed during dangerous situations. Providing retrospective feedback can influence future driver behavior. The driver can learn what constitutes safe driving, when not to engage in distractions, what speed to maintain in different driving conditions, and how to diminish risk for future trips.

Drivers can only attend to concurrent and delayed feedback for very short periods, making it impossible to provide detailed information regarding an event that triggers feedback. As a consequence, concurrent or delayed feedback may not be able to convey the information necessary to understand the reason for feedback. For example, if there is a relationship between two driving incidents that occur at different times, then presenting this link via concurrent or delayed feedback may be too complex for the driver to interpret while driving. However, this information can be useful in helping drivers assess their overall driving performance by highlighting the persistent behavior that leads to errors. In the absence of feedback, drivers tend to forget their roadway incidents very quickly. Chapman and Underwood[24] found that an estimated 80% of near-accidents are forgotten after 2 weeks. This suggests that driver behavior may be changed by refreshing drivers' memory of their driving performance as well as calibrating their subjective performance (i.e., how safe they think they drive). This information or feedback may be better presented retrospectively.

29.2.5 Cumulative Feedback

Cumulative feedback is a comprehensive summary of past driving performance and driver behavior and is not provided during driving. Cumulative feedback integrates driving data over many trips that may span several weeks or months. Similar to retrospective feedback, cumulative feedback has the potential to change driver behavior. Both retrospective and cumulative feedback can present information on several incidents over time. This can help the drivers assess their overall driving performance by highlighting those persistent behaviors that lead to errors.

McGehee et al.[25] examined the effects of feedback on training teenage drivers in a naturalistic driving study. An event-triggered video device was installed in each vehicle that recorded abrupt driving maneuvers and these events were reviewed weekly with parents for approximately 6 months. The data from 26 teenage drivers showed an 89% decrease in the number of incidents for the more at-risk teen drivers. In addition, the effect of this feedback persisted even after the device was removed. This suggests that cumulative feedback can lead to lasting behavioral changes. However, because there was no baseline group that was also monitored for 6 months (i.e., drivers with no feedback), more research is still needed to assess the exact benefits of such feedback. Neither retrospective feedback nor cumulative feedback has been systematically studied in the driving domain, and both require further research (see Refs 25 and 26 for some preliminary examples). For example, the effectiveness of cumulative feedback should be investigated to determine the most appropriate time lag between the event and feedback.

29.3 COMBINATIONS OF DIFFERENT FEEDBACK TIMESCALES

Feedback mechanisms need not be mutually exclusive. The little research that has considered feedback timing at different timescales has compared one level to another, but has not assessed the potential benefits of providing both levels together. Presenting feedback at multiple timescales can provide redundancy and refresh a driver's memory of an incident. This redundancy is useful since, as already noted, there is research that suggests that drivers forget the majority of near-accidents very rapidly.[24] Combined feedback timescales can also complement each other in enhancing performance and changing behavior. For example, providing concurrent feedback in the form of a short alert cannot explain the specific problems associated with changing lanes while simultaneously talking on a cell phone in a congested area. This can be better conveyed in more detail as retrospective feedback. However, concurrent feedback can indicate that some response is needed immediately.

Another advantage of combining feedback timescales is that receiving feedback in shorter timescales can help the driver understand feedback over longer timescales. However, this support may diminish as the time between the feedback increases. For example, concurrent feedback provided for an incident and cumulative feedback provided weeks or months later regarding the same incident may not be easily connected by the driver. If concurrent feedback has been strengthened in memory by the help of retrospective feedback, the driver can better relate cumulative feedback to a particular incident. For the driver to easily relate to different feedback timescales, the representation of feedback should promote a consistent mental model.[27] For example, if a high level of distraction is presented with an orange warning light for concurrent feedback, then this color should also be used in retrospective feedback for the same information.

29.4 FEEDBACK TIMING AND FEEDBACK TYPE

The type of feedback can have different influences on the effectiveness of each feedback timescale. Feedback provided to the driver can be positive or negative.[28,29] Positive feedback is provided for correct actions.[30] Negative feedback is provided for errors and includes error flagging, directive feedback, and explanatory feedback[28,31]: (1) error flagging includes acknowledging and identifying the error occurrence; (2) directive feedback includes providing instructions on how to correct the error; and (3) explanatory feedback includes diagnosing the misconceptions that generated the error and setting new goals that remediate the error, and correct misconceptions. Error flagging and directive feedback can be presented concurrently, whereas explanatory feedback would require more time and resources from the driver and be more appropriately presented retrospectively. For example, if the driver's distraction level increases beyond a threshold, a real-time alert (i.e., error flagging) can be provided, and the explanations for the alert (e.g., too many off-the-road glances to a navigational display) can be provided to the driver immediately after the trip is over.

Kluger and DeNisi[32] state that participants who receive negative feedback are likely to exert more effort than those who receive positive feedback. In some situations, negative feedback may be necessary to educate the driver about risky driving patterns. For example, if drivers deviate from their lanes, providing a warning can help avoid a collision. Retrospectively pointing out the number of lane deviations during a trip can help the drivers understand how unsafe their driving is. However, too much negative feedback can undermine driver acceptance of feedback. Positive feedback, on the other hand, promotes acceptance. For example, workers accept an ergonomic intervention more, for which they have to learn to perform their jobs in a new way, if they are provided with positive feedback (e.g., providing feedback on increased productivity or on better posture).[33] Fogg and Nass[34] found that people who received random positive feedback during a computer game thought the interaction was more enjoyable and were more willing to continue working with the computer than people who did not receive any feedback. The results were the same even when participants were told that feedback was unreliable. Participants liked the computer better when it praised them even if they were told that the feedback was unreliable, compared with when it criticized them.[35]

Including positive feedback in addition to negative feedback can help change drivers' attitudes toward the technology. If feedback is provided over a longer timescale (e.g., retrospective and cumulative), then driver acceptance is critical. Otherwise once a trip is completed, drivers can leave their cars without receiving retrospective or cumulative feedback on their performance. Toledo and Lotan[26] investigated driving performance over a 5-month period as influenced by cumulative feedback presented on a personal web page. Using this page, drivers could access the information on all their previous trips and also receive information about the performance of other drivers. Initially, feedback improved safety, but this effect diminished over time as the drivers accessed their web pages less frequently. One approach to improve participation is to include positive feedback. For example, a driver's acceptance of retrospective feedback can be enhanced if feedback also praises the driver for safe driving maneuvers, such as abiding speeding limits and maintaining safe following distances, in addition to presenting any unsafe driving maneuvers.

29.5 CONCLUSION

Most of the research in the driving domain considers only the ability of immediate feedback to mitigate distraction and enhance driving performance. In addition to enhancing immediate performance, feedback can also promote safer long-term driver behavior. The effects of feedback on immediate driving performance can be observed in performance measures such as braking, speed variation, and time headway maintenance. The long-term changes in behavior that result from feedback may be better awareness of certain safety critical situations, greater responsiveness to the roadway environment, and diminished willingness to engage in various types of distracting activities. Concurrent and delayed feedback can have the greatest effect on immediate driving performance, whereas retrospective and cumulative feedback can have a greater effect on long-term behavior. The combination of concurrent feedback and feedback at longer timescales may have more powerful effects than either type of feedback alone. Owing to the very limited number of studies on different feedback timescales, many of these assertions are based on theory, not empirical evidence. Future research should compare different feedback timescales and assess their relative influence on short-term and long-term driving behavior. In addition to establishing the most appropriate timing of feedback for a given situation, research is needed to determine the pairing of the type of feedback with the timing of the feedback.

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Edited by

Michael A. Regan

John D. Lee

Kristie L. Young

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PART 8 Prevention and Mitigation Strategies

PART 9 Conclusions